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RESEARCH PAPER

Using a Small-Log Mobile Sawmill System to Contain Fuel Reduction Treatment Cost on Small Parcels

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Abstract The Authors tested a mobile small-log sawmill system that could produce cants and boards of variable size, according to the needs and specifications of each property owner. The unit was deployed as part of a comprehensive mechanical fuel reduction operation, aimed at thinning small properties around homesteads. Working on conifer small logs, the mill proved very efficient, with a processing productivity between 0.3 and 2.8 m^3 of lumber per working hour and a recovery rate of 50% for boards, and 67% for cants. The mill could be set up and dismantled in a few hours and was easy to move around. However, the exceedingly small amount of logs available at each site entailed a low utilization of the mill (about 25% of the time) and a consequently high processing cost. Under the conditions of the study, milling cost can be contained below 150 US dollars per m^3 of lumber only if the single site offers at least 50 m^3 of logs, already sorted during harvesting. Hence the suggestion of pooling the wood obtained from small parcel fuel reduction treatments in satellite yards and milling it only when a large enough amount has been

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accumulated. In turn, satellite yards could be organized into an integrated network complementary—rather than alternative—to stationary mills.

Keywords Mobile sawmills · Fuel reduction · Small wood · Thinning operations

Introduction

Catastrophic wildfires have become an increasingly serious threat to forests and communities in the western United States. The wildland-urban interface is especially vulnerable, as it associates a high fire risk with a high potential for damage to property and lives: here, one must create a defensible space by reducing the amount of fuel surrounding the house. The presence of a defensible space will enable firefighters to operate safely and effectively. Fuel reduction, however, can be rather expensive, so owners are often discouraged from fireproofing their properties (Rummer 2008).

Fuel treatment may include a harvesting component that, although not profit-driven, can help reducing the cost of the entire operation (Fiedler et al. 1999). However, forested properties associated with homes are often too small for cost-effective harvesting and fuel treatment performed with the traditional methods and equipment used in commercial operations, such as feller-bunchers and skidders (Lyon et al. 1987). Moreover, forest law requires the preparation of a timber harvest plan if products are sold or bartered. Under current conditions, timber harvest plan development is costly and not practical for parcels smaller than 4 hectares. The Californian law provides for timber harvest plan exemptions which enable a landowner to use the products of the fuel reduction treatment. The most appropriate exemptions are: (a) removal of hazardous fuel within 50 m of a home and (b) removal of less than 10% of total volume of standing timber. In these cases, timber harvest plans are not necessary, if the owners keep the wood for their own use, neither selling nor bartering it.

The goal of this study was to test an alternative approach to fuel treatment that may respond to the needs of small-parcel owners. The tested system included a mobile small-log circular sawmill that could produce cants and boards of variable size, according to the specifications of each property owner. According to the same small-scale philosophy, harvesting was also carried out by a light single-machine system capable of working on small parcels and in dense forest conditions (Windell and Bradshaw 2000) rather than a standard mix of heavier logging equipment. The results of the harvesting study are being published as a separate report (De Lasaux et al. 2009).

Previous studies have highlighted the potential of mobile sawmill systems in adding value to the product obtained from small parcels (Stewart 1999). However, obtaining good productivity with small logs is very difficult, because the time required to handle one log is excessively long when compared to the amount of lumber obtained from it. Many mobile sawmills are built around a single band saw or disc, and require several passes to process one log. The result is a low-production operation, which has difficulty competing with a stationary multiple-saw small-log

mill, despite the savings in transportation cost. Small-log mobile sawmills with higher productivity are needed to complement traditional mills when the latter are not capable of processing small diameter timber profitably (Mackes and Lynch 2000). The sawmill selected for the study was the Economizer, a mobile mill built by the Canadian firm, Micromill Systems Ltd. This trailer-mounted mill can be towed by a large pickup truck, allowing for frequent relocation with minimum downtime, which is crucial when dealing with small parcels. The Economizer is specially designed to handle small logs, such as those obtained from fuel reduction operations. Being a chip-n-saw mill, the Economizer processes each log fed into the mill in a single pass: the log is first squared by the chipping-head assembly and then cut into boards by gang arbor ripsaws. The specifications of the mobile sawmill are presented in Table 1. Chip-n-saw mills of this type are particularly effective with small logs (Darr and Fahey 1973; Vickers 1998). The study focused on quantifying the reliability, the productivity and the yield of the mobile sawmill system under variable conditions, in order to provide directions on its most effective use. In particular, the goals of our research were to determine: (1) operation gross productivity and cost, (2) lumber recovery for a range of log sizes and (3) lumber yield for the tree species and the tree size typically obtained from fuel reduction operations conducted in the mixed conifer stands of the Northern Sierra Nevada and Southern Cascades mountains. This research is of particular interest, since very few scientific studies are available on mobile sawmill systems, despite the relative success of these units, as witnessed by the over 35 manufacturers currently represented in the US (Clement 2008).

Materials and Methods

Milling trials with the Economizer mobile mill were conducted from March 28 to May 14, 2003 on four sites (Table 2) in northeastern California. The sites were selected from a much larger pool inspected and characterized during the previous year. The selected sites were considered representative of many of the small parcels of the Northern Sierra Nevada and Southern Cascades.

All stands resulted from natural regeneration after logging or fire. Mixed-conifer stands were the most common, with various proportions of Douglas-fir (*Pseudotsuga menziesii Mirb.*), white fir (*Abies concolor Lindl.*), ponderosa pine (*Pinus ponderosa Law.*) and incense cedar (*Calocedrus decurrens Torr.*).

Table 1 Machine description

Power unit	118 kW Perkins diesel
Weight	5,400 kg
Trailer length	6 m
Canter	4 Chipping cutterheads
Splitter	Gang arbor rip saw
Log diameter range	7.5–25 cm
Maximum log length	6 m
Saw kerf	4 mm

Table 2 Description of the test sites

	Site			
	NEV1	NEV2	SHA3	SIE1
Nearest community	San Juan ridge	Nevada city	Shingletown	Loyalton
County	Nevada	Nevada	Shasta	Sierra
Area (hectares)	1.04	1.52	1.36	0.72
Species	Mixed conifer	Mixed conifer	Mixed conifer	Ponderosa
Harvested trees	185	106	118	336
Dbh, cm., mean (range)	16.5 (10–28)	16.2 (10–28)	17.3 (10–28)	14.9 (10–28)
Height, m, mean (range)	14.5 (7.3–24.0)	13.7 (9.5–24.5)	11.3 (7.2–20.7)	9.9 (7.4–16.5)
Total harvest (m^3 roundwood)	23.7	13.9	11.4	23.8
Logs milled (n°)	186	281	108	613
Lumber (m^3)	6.2	5.6	4.3	9.4
Assortment	Boards	Boards	Cants	Boards

The average area treated per site was 1.16 hectares, yielding averages of 186 trees and 18 m^3 of logs. Not all logs were converted into lumber, however. The owners would often set aside part of the harvest for specialty products needed on the property, such as round poles or firewood. On average, 6.4 m^3 of lumber was produced per site.

The work proceeded as follows. After the trees were harvested and the logs skidded to and stacked at a landing, the mill was moved to the site and set up. If necessary, logs were sorted. Then sawmilling began, generally lasting a few hours. Lumber was stacked, stickered and banded. Finally, the sawmill was dismantled and loaded, and the operation moved to a new site. The milling operation included the Economizer mill, a small skid-steer loader, a trailer for the skid-steer loader, a heavy pickup truck to alternatively tow the Economizer and the trailer with the skid-steer, and a light pickup truck for general use. The work was conducted by two operators, who assisted each other while sorting with the skid-steer loader and then positioned themselves respectively at the log infeed and lumber outfeed when sawing. Both operators had considerable skill and experience, having worked with the machine for 4 years.

The research presented in this paper consisted of a time-motion study to quantify the productivity of the Economizer mill, and concerned the activity of the mill system including the truck used to relocate it and the skidsteer loader detached to load logs onto the mill deck and to stack milled lumber. Recorded activities included milling, as well as mill dismantle, relocation and set-up.

In addition, a sample of the logs fed to the mill were marked with code numbers and characterized by recording species, total length, small end diameter inside bark (SEDIB) and large end diameter inside bark (LEDIB). The sample contained 84% of the total number of logs being processed by the mill during the tests, i.e., 998 logs out of 1,188. The processing of numbered logs was stop watched individually. Data were recorded on a Husky Hunter running the Siwork 3 time-study software. Each record contained the time for processing one log, the serial number of the log and

Table 3 Description of time elements

Time element	Description
Charge	The skidsteer loader picks up the logs from the deck and loads them on the log chain. Ends when the sawmill is started again and the log chain starts moving.
Load	Logs are pushed by the log chain into the singulator, which kicks one log onto the infeed rail. The log is pushed forward on the rail and into the sawmill. Ends when the first two feed wheels engage the log. May include a stop to check log diameter.
Adjust	The loading routine is interrupted to change the settings of the chipping heads, generally in a few seconds by using buttons on the control panel. Ends when loading is resumed.
Mill	The log is being milled. Begins when the first two feed wheels engage the log and ends when they engage another log or when the lumber has exited the saw tunnel.
Stack	The lumber is stacked and stickered. This is only a residual time, since one of the two operators is just stacking most of the time, and this element gets recorded only when the stacker lags behind and the other operator interrupts milling to assist.

the type (cants or boards), number and sizes of lumber produced. Process time was divided into elements, described in Table 3. Detailed time and motion studies of this type allow relating machine performance to job characteristics, which is very useful when trying to predict operational productivity under variable conditions (Bergstrand 1991). Delays were also recorded, providing the basis for an assessment of the reliability of the machinery as well as the efficiency of the system.

Recovery was estimated by comparing the volume of the lumber products obtained from each individual log with its original volume. Comparison at the individual log level allowed exploring the eventual relationships between lumber recovery, species, log size and lumber product type. The diameter at breast height (dbh) and total height of the trees that originated each log/set of logs had been recorded in advance, so that tree utilization could also be estimated. Overall, the sample contained 446 trees.

Machine operating costs have been calculated using Miyata's (1980) costing method. The primary assumptions are a depreciation period of 5 years, a salvage value of 30% of the initial price and a service life of 10,000 scheduled machine hours (SMH). Different rates were calculated for the whole system (mill and truck) for application to productive time and relocation time: this was done on the assumption that during productive time the truck accrues no fuel and maintenance cost, and that the same is true for the mill during dismantle, relocation and set-up. The machine rates thus obtained were increased by 10%, to account for overhead costs (Hartsough 2003). The details of machine and system costs are shown in Table 4.

Results

The total time recorded for the Economizer during the study amounts to 74 h, excluding meal time—i.e., more than nine 8-h workdays (Table 5). This figure includes productive work, relocating the operation, set up, dismantle and maintenance.

Table 4 Machine and system cost, according to activity type (mode)

Activity	Machine	Initial investment ($)	Service life (years)	Usage (SMH)	Crew (n°)	Fuel ($ SMH^{-1})	Repair ($ SMH^{-1})	Fixed cost ($ SMH^{-1})	Variable cost ($ SMH^{-1})	Total cost[a] ($ SMH^{-1})
Work mode	Mill	400,000	5	10,000	1	2.6	21.0	36.6	49.5	94.8
	Skidsteer	50,000	5	10,000	1	1.0	2.6	4.6	28.9	36.9
	Truck	60,000	5	10,000	0	0.0	0.0	5.5	0.0	6.0
Whole system										137.7
Relocation mode	Mill	400,000	5	10,000	0	0.0	0.0	36.6	0.0	40.3
	Skidsteer	50,000	5	10,000	1	1.0	2.6	4.6	28.9	36.9
	Truck	60,000	5	10,000	1	1.0	3.1	5.5	29.5	38.5
Whole system										115.7

[a] *Note*: Total cost includes a 10% overhead charge, calculated over the sum of fixed and variable cost

Table 5 Time consumption (hours) by activity and site

Activity	Site									
	NEV1		NEV2		SHA3		SIE1		All sites	
	Hours	%	Hours	%	Hours	%	Hours	%	Hours	%
Travel	8.0	29	4.2	32	3.0	33	9.3	38	24.4	33
Setup	5.7	21	1.7	13	1.8	20	4.4	18	13.5	18
Sort	4.7	17	0.4	3	1.0	11	0.0	0	6.1	9
Mill	4.3	16	5.3	40	1.7	18	7.4	30	18.6	25
Dismantle	1.0	4	1.1	8	1.7	18	1.5	6	5.3	7
Maintenance	3.7	13	0.6	4	0.0	0	1.9	8	6.2	8
Total time	27.3	100	13.2	100.0	9.1	100	24.5	100	74.1	100

The average time required to treat a single parcel was 18 h, but there were wide differences between sites, due to travel distance, amount of lumber to be milled and ease of access to the landing.

Figure 1 shows the share of total time consumption according to the activity performed. Productive work (sorting and milling) constituted only one-third of the total time consumption, due to the very small amount of wood available at each site. Travelling between sites also accounted for one-third of the total time consumption. This was related to the relatively long distances between test sites (average 91 km) and to the fact that each mill relocation required three-one-way trips: the first to move the mill, the second to return to the previous site to collect the skid-steer and the third to move the skid-steer to the new site. Faster moving could be obtained by

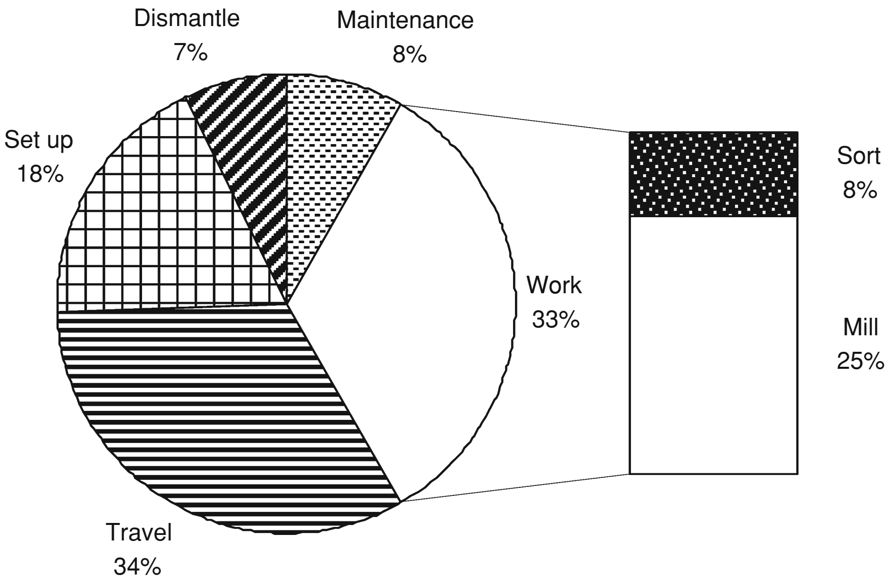

Fig. 1 Activity breakdown: percent incidence over total work time

upsizing the second truck so that it could tow the trailer with the skid-steer: this would reduce relocation time by about two-thirds.

Set up and dismantle were quick: they took 4.7 h per site, but still represented 25% of the total time consumption, due to the relatively short duration of the work conducted on each set up. There were large differences between sites: set up and dismantle time averaged 6.3 h at the two sites with the most difficult access (NEV1, SIE1) and dropped to 3.1 on the other two, where good landings were available.

A similar grouping could be made for sorting time: at NEV2 and SIE1 the logs had been sorted beforehand by the logging crew, while at NEV1 and SHA3 the logs had to be sorted by the mill crew.

Maintenance time mostly involved the truck, which suffered a couple of breakdowns, including a flat tire. The mill itself showed excellent reliability during the study.

Recorded data help appreciate the potential of the Economizer sawmill: as promised by the manufacturer, this proved reliable, could be set up and dismantled in a few hours and, once it was running, produced an average of 1.3 m^3 of lumber per scheduled hour.

Cycle time data for milling were analyzed statistically to obtain meaningful relationships between time and independent variables. The equations obtained are all significant at the 0.0001 level. No meaningful relationship was found between the time to charge the mill deck with logs and any of the tested independent variables, which is logical since charging was not cyclic, but occurred in bouts. The average charge time was 3.8 min^{-100} per log. The time for loading a log on the mill line had a very weak ($R^2 = 0.032$) but significant correlation with log size, whereas that for adjusting the mill settings could not be related to any of the measured independent variables. The time for adjusting the spacing of the chip heads is almost constant, and its average value is 21.9 min^{-100}. What actually changes is the frequency of adjustments, which depends on the variability within the batch of logs to be processed, and therefore on the precision of sorting. Therefore, data were organized by site and grouped according to the estimated sorting quality achieved on each site. Finally, two different adjustment frequencies were calculated and adopted into the model: every 7.7 logs in case of good sorting/low log variability and every 2.9 logs otherwise. Milling time is strongly correlated ($R^2 = 0.532$) to log volume and length, and is described by the following equation: min^{-100} per log = 6.04 + 452.49 Log Volume (m^3) + 6.99 Log length (m). Stacking time increases with the amount of lumber to be stacked, according to the following relationship: min^{-100} per log = −0.445 + 66.05 * Lumber Volume (m^3). The very weak correlation ($R^2 = 0.012$) relates to the fact that the recorded stacking time was a residual time only: one of the two operators was stacking most of the time, and the stacking element by our definition only involved time when the other operator had to interrupt milling and assist.

These equations provide net work time, excluding productive delays which averaged 13% of the total work time. Net productivity can be transformed into gross productivity using a 0.87 factor.

Lumber recovery averaged 50% for boards and 67% for cants. Summary data are shown in Table 6. A multiple regression analysis was developed for predicting

Table 6 Log and lumber recovery data by species, means (ranges in brackets)

Species	Logs	Recovery (%)	Log length (m)	SEDIB (cm)	Taper (cm m^{-1})
All	909	51.1 (16.9–100.6)	3.0 (1.9–4.5)	11.4 (5–23)	0.9 (−1.2; 3.8)
Cedar	73	49.8 (28.3–90.3)	2.9 (2.1–4.4)	10.7 (5–20)	1.2 (−1.2; 2.9)
Douglas Fir	185	59.4 (16.9–100.6)	3.6 (2.0–4.5)	12.4 (5–23)	0.7 (−0.6; 2.8)
White Fir	25	71.2 (41.6–100.6)	3.4 (2.6–3.9)	12.4 (7–18)	0.9 (0.0; 1.6)
Ponderosa	624	47.8 (20.4–93.8)	2.8 (1.9–4.0)	11.4 (5–23)	1.0 (−0.9; 3.1)

lumber recovery as a function of log length, stem taper, product type and board thickness. The equation obtained has a rather weak correlation coefficient ($R^2 = 0.182$), but all independent variables are significant at the 0.001 level. Its form is: Recovery rate (%) = 82.57 − 43.79 Board Dummy (1 if boards, 0 if cants) − 4.22 Taper (cm m^{-1}) Log length (m) + 3.34 Board Dummy * Taper * - Length + 4.24 Board Dummy * Board thickness (cm). This equation was used to calculate recovery as a function of log length by product type for the average taper (1 cm m^{-1}) and a board thickness of 2.5 cm (Fig. 2), or as a function of taper for a 3 m log length by a board thickness of 2.5 cm (Fig. 3). Both graphs show the remarkable difference between cants and boards, the former allowing for a much higher recovery. By combining this equation with the models used for predicting milling time, one can calculate the milling productivity of the Economizer. Figure 4 shows productivity as a function of SEDIB by product type for 3 m long logs, with average taper. For boards, a 2.5 cm thickness was assumed. The graph also highlights the higher productivity obtained when producing cants: this does not depend on a faster milling rate, but on a higher recovery. The time to mill a log of a given size is the same regardless of the product obtained, but the lumber output is higher when turning it into cants, hence the higher productivity.

The tree data were analyzed and relationships were developed to predict lumber yield as a function of tree characteristics (Table 7). To date, no volume tables are available for the small trees obtained from fuel reduction operations, which makes it

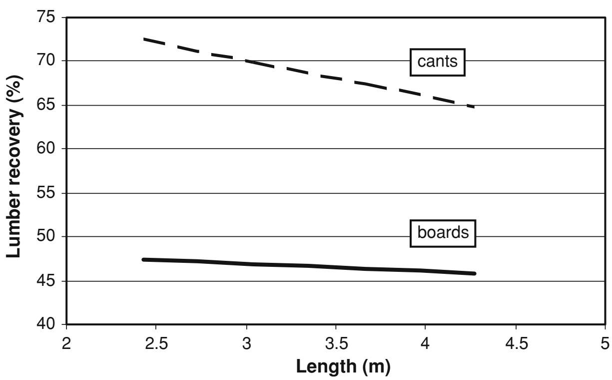

Fig. 2 Lumber recovery as a function of log length and product type. *Note*: board thickness was 2.5 cm and taper 1 cm m^{-1}

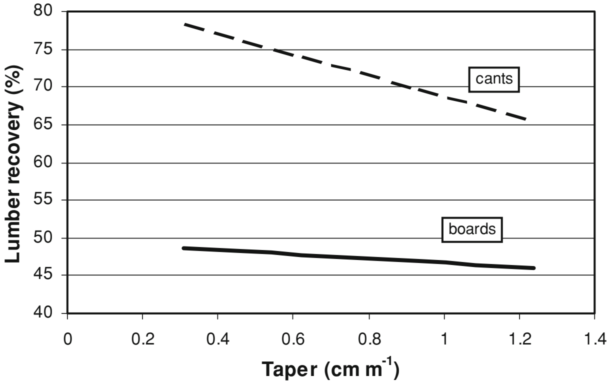

Fig. 3 Lumber recovery as a function of taper and product type. *Note*: board thickness was 2.5 cm and log length 3 m

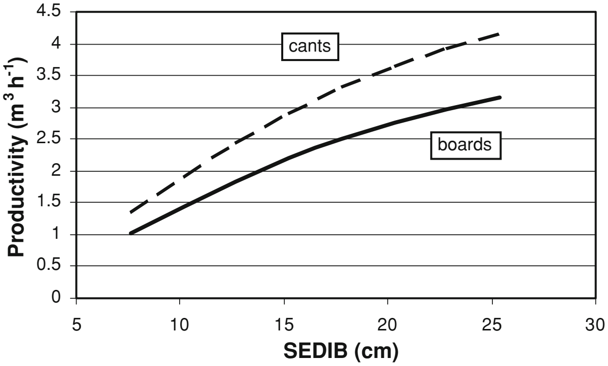

Fig. 4 Milling productivity (incl. delays) as a function of SEDIB and product type. *Note*: board thickness was 2.5 cm and log length 3 m

Table 7 Lumber yield for small trees from fuel reduction operations (dbh 10–28 cm)

Species	Trees	Lumber yield, m^3	R^2	Note
Ponderosa	273	$0.000094 * \text{dbh, cm}^{1.419} * H_{7.5}, \text{m}^{1.010}$	0.916	Boards only
Douglas Fir	98	$0.000232 * \text{dbh, cm}^{1.423} * H_{7.5}, \text{m}^{820}$	0.777	Boards only
Cedar	34	$0.000191 * \text{dbh, cm}^{1.239} * H_{7.5}, \text{m}^{848}$	0.853	Boards only
White Fir	17	$0.000401 * \text{dbh, cm}^{.509} * H_{7.5}, \text{m}^{1.290}$	0.892	Cants and boards

Note: $H_{7.5}$ = Stem length to a 7.5 cm topping diameter

very difficult to estimate the amount of product available for partly offsetting treatment cost. The equations obtained from this study are therefore important for planning fuel treatment operations.

Under the cost assumptions shown in Table 4, the cost of the whole operation was estimated to 123 USD SMH^{-1} (weighted average of milling time, relocation

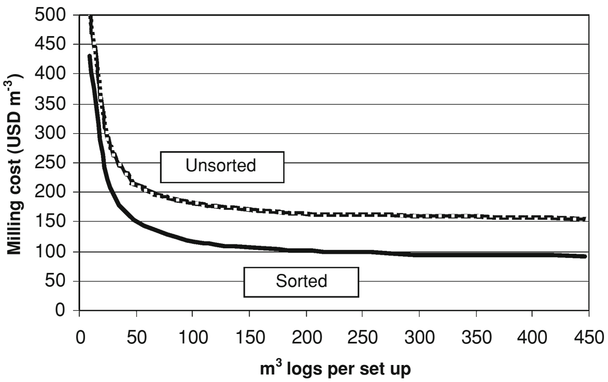

Fig. 5 Milling cost as a function of log volume per site, for board milling. Figures have been calculated using the models described in the text, for 3 m-long logs with a 12 cm SEDIB, milled into 3.8 cm thick boards

etc.) For the average recorded productivity of 0.3 m^3 of lumber per scheduled gross hour, the milling cost was 410 USD m^{-3}, including stacking and banding. This number is heavily burdened by the high incidence of moving time.

Figure 5 shows the variation of milling cost with the log volume accumulated at a single site. The calculation has been conducted for a relocation distance of 80 km, and shows that under these conditions, a meaningful cost reduction is obtained only if the single site offers at least 50 m^3 of logs (about 1,000 logs), corresponding to 14–24 h of milling depending on whether the logs have been sorted or not. If the logs have already been sorted, milling cost decreases by 20–40%.

Discussion and Conclusions

The Economizer is a mobile sawmill especially designed for handling small logs, such as those obtained from fuel reduction operations. It is reliable, can be set up and dismantled in a few hours and is very productive for a mobile plant. After the logs have been sorted, the mill can process between 0.8 and 2.8 m^3 of lumber per working hour, depending on log size and job type. This productivity is much higher than that obtained with simpler set ups (Venn et al. 2004), that are most common among mobile sawmilling operations. Such result is obtained through a specific tool choice (chip-n-saw assembly) and a certain level of routine standardization, which makes processing less flexible than it is with simpler units. The economizer seems particularly well suited to the processing of regular-shape small logs, and to the production of few different lumber products. When dealing with large, crooked or irregular logs—especially hardwood—then a simpler machine might be a better choice, although both productivity and lumber recovery will be much inferior. In fact, the recovery rate obtained with the Economizer is quite high for a small mobile plant, and exceeds that obtained with stationary chip-n-saw mills under similar small-log conditions (Fahey and Hunt 1972).

All the above makes the Economizer a miniature industrial plant, suitable for installation on temporary sites and not as a typical mobile sawmill for the wandering part-timer. That emphasizes the need for accumulating a certain amount of wood at each site: below such critical level, hauling to a stationary plant may still be the most economic choice.

Small parcels such as those included in this study present very difficult work conditions: both the trials and the above calculations clearly show that the amount of wood processed on each of the test sites was too limited for cost-effective operation. The Economizer has a relatively high investment cost, explained by its high-output industrial design: its potential cannot be fully exploited if the machine is milling only a quarter of the time. In fact, non-productive time can be reduced by upsizing the second truck in the operation, so that re-location requires only one trip instead of three. Besides, sorting should be done in advance, before the mill arrives on site and not when a 40 USD SMH^{-1} machine sits idle. Such improvements could succeed in bringing sawmill utilization above the 40% level, which is a good result, yet probably sub-optimum.

The situation can be dramatically improved by pooling the wood obtained from small parcel fuel reduction treatments in satellite yards and processing it only when sufficient volume has been accumulated. This would involve additional costs to load and transport logs to the yards, and to haul the milled lumber back to the originating sites if is to be utilized by the owners. In fact, logistics could be optimized by cooperative management, for which such plant seems particularly suited (Rauch and Gronalt 2005). In turn, satellite yards could be organized into an integrated network complementary—rather than alternative—to stationary mills (Smorfitt et al. 2003). In this case, milling cost can be driven below 100 USD m^{-3} of lumber.

The relationships highlighted in this study can assist managers to take decisions about the eventual purchase and/or the best deployment strategy. These equations were organized into a spreadsheet model that can estimate productivity and cost as a function of log characteristics, moving distance and site conditions. Interested parties can ask for a copy of the model to any of the Authors.

Acknowledgments We'd like to thank the landowners who participated in the study and the mill operators.

Appendix

See Table 8.

Table 8 Table of notations

m^3 = Cubic meters
DBH = Diameter at breast height
SMH = Scheduled machine hours
SEDIB = Small end diameter inside bark
LEDIB = Large end diameter inside bark
USD = United States dollars

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